AMENDMENT TO THE SPECIFICATION

Please amend the following paragraph at page 11, lines 1-2:

Figure 7 is a plot of viscosity (Cp) (vertical axis) versus temperature (horizontal axis) for various experiments; [[and]]

Please amend the paragraph at page 11, line 4 as follows:

Figure 8 is a plot of viscosity (Cp) (vertical axis) versus temperature (horizontal axis); and

Figure 9 is a block diagram depicting a boiler system according to an embodiment of the present invention.

Please insert the following paragraph at page 14, line 1:

Figure 9 depicts a boiler system 900 according to an embodiment of the present invention. The system 900 includes a pulverizer 904 to crush the coal 902 to the desired size. The crushed coal is provided to a fuel transfer system 908, in which the iron-containing additive is combined with the crushed coal. The fuel transfer system 908 pneumatically transports the mixture of iron-containing additive and crushed coal to the cyclone boiler 912. The mixture is introduced into a burner 916 in the cyclone boiler 912. In the cyclone boiler 912, the coal is trapped and burns in a layer of slag 928 coating the walls. The slag 928 and other combustion products, such as off-gas 920, exit the cyclone boiler 912.

Please insert the following text at page 18, line 10, of the specification.

In yet another embodiment, the use of inexpensive iron-bearing byproduct material is used to provide a less costly fix to the problems arising from using low sulfur coals in cyclone boilers. In addition to being less expensive, the physical characteristics of these materials provide additional benefits that potentially make them more effective than the other sources of iron. However, to provide an effective system for enhancing combustion in cyclone furnaces, there are several

important steps in this process including proper selection of candidate material, treatment of the dust to allow handling and shipping, blending with the coal, and control of the feed rate.

This process is applicable for use in the coal-fired electric utility industry. It is specifically of use for utilities that employ cyclone furnaces to fire low iron, high-alkali coals such as those found in the western regions of the United States. The invention may also be extended by those skilled in the art to apply to any industrial boiler that produces a molten, liquid ash residue (known to the industry as "wet-bottom" boilers).

As noted previously, cyclone furnaces are used to generate steam for power production and industrial processes. Such a furnace is diagramed in Figure 1. The furnaces operate by maintaining a sticky layer of fluid ash (slag) on the inside walls of the cyclone combustor. Coal is crushed to a 1/4-inch top size and blown into the burner end of the cyclone combustor. The whirling motion of the combustion air (hence the name "cyclone") propels the coal toward the furnace walls where the coal is caught like flies in flypaper and burns in the slag. Products of combustion exit the cyclone through an opening called the re-entrant throat at the opposite end from where the coal was introduced. Molten slag flows slowly through a spout to a hole in the bottom of the boiler where it is water-quenched and recovered as a saleable byproduct. The ash composition is critical to prevent the slag from freezing in the hole and causing pluggage. Therefore, cyclone furnaces were located in the mid-west to burn local high-sulfur, high-iron coals. Over time, cyclone furnaces have been converted to burn low-sulfur coal to satisfy environmental regulations limiting SO_2 emissions.

When certain high-calcium, low-sulfur coals from the Powder River Basin of Montana and Wyoming are burned in these furnaces, the cyclones do not develop a thick enough layer of sticky slag and the coal is not caught. This poor slag coating leads to unburned coal, degraded performance of particulate collectors (leading to stack opacity violations), and increased fuel and maintenance costs. The sticky slag layer can be reestablished by increasing the iron content of the coal.

It has been known for many years that iron is an effective fluxing agent for certain alumino-silicate glasses. Iron oxide fluxes high-silica glass, while reduced forms of iron (FeO or Fe-metal) flux calcium-rich glass. In the presence of burning coal particles, iron exists primarily in

reduced form. Its use has been recommended to solve slag-tapping problems in cyclone furnaces by either blending in high iron coal or adding commercially available iron pellets, both of which are very expensive. The pellets (due to their size) have a further disadvantage of forming pools of reduced iron that can be very corrosive to metal or refractory surfaces exposed to it. Therefore, iron fluxes have never achieved long term acceptance in the utility industry.

The use of inexpensive iron-bearing byproduct material is a novel means to provide a less costly and technically superior fix to this problem. In addition to being less expensive, the physical characteristics of these materials provide additional benefits that potentially make them more effective fluxes than commercially available sources of iron.

It is the object of this embodiment of the present invention to improve the performance of cyclone furnaces burning low-iron, high-alkali coals by enhancing the slagging characteristics of the ash through the addition of low-cost iron byproducts.

However, to provide an effective system for enhancing combustion in cyclone furnaces, there are several key steps in this process including:

- proper selection of candidate material,
- treatment of the dust to allow handling and shipping,
- design of equipment to blend the flux with the coal,
- design of a control system to adjust additive feed rate.

It is the use of these byproducts of steel and iron manufacturing to flux the ash and improve the cyclone operation that is new and unique.

Several candidate byproduct materials are available to provide a source of iron that can be technically acceptable, such as:

- Basic Oxygen Furnace (BOF) flue dust or precipitator fines
- Blast Furnace flue dust
- Electric Arc Furnace dust
- Mill Scale fines

The materials are generally more than 50% iron by weight and are dusty or powdered. The preferred embodiment of this invention uses iron-bearing waste products containing more than 80% iron. Also, sludges containing iron plus oils and greases produced during metal finishing operations are suitable. These materials have the advantage of preventing fugitive emissions during handling and shipping. In addition, combustion of the oil or grease is also of value to boiler operators by replacing the heat input requirement from the coal and thus reducing fuel costs for producing electricity. An additional source of iron-bearing material is red mud from the bauxite mining industry.

The most favorable material was found to be flue dust and electrostatic precipitator dust from blast furnaces or BOFs. These are very fine dusts collected from iron or steel making furnaces. The material contains primarily Oxides of Iron and other metals in small amounts.

The elemental analysis of BOF flue dust was used to model its effect on PRB coal ash viscosity and the subsequent effect on the cyclone slag layer. The slag viscosity model showed that the BOF flue dust, when added to the coal to increase the ash iron percentage to 30% by weight, increased the thickness of the sticky layer in the cyclone by about 60%. The model also showed that the temperature at which the ash would have a viscosity of 250 poise would be reduced by at least 100°F. This temperature is an important indicator of the minimum temperature at which the slag will flow. If the temperature at which the ash has a viscosity of 250 poise or lower is too high, then the slag will not flow to the slag tap on the floor of the boiler and will build up inside the boiler casing. This has been a problem on cyclone furnaces burning western coal at less than full design output.

Further, experience has shown that the presence of iron in the calcium aluminosilicate slags causes crystal formation in the melt when a critical temperature (T_{cv}) is reached. These crystals change the flow characteristics of the slag causing it to thicken before it can flow. This phenomenon is known as "yield stress" and is familiar to those skilled in the art of non-Newtonian flow. Thicker slag allows the slag to capture and hold more coal particles. Therefore, much fewer coal particles escape the combustor without being burned.

To Applicant's knowledge, the alternatives when burning Powder River Basin coal in cyclone furnaces are to blend other more expensive coals which have high iron, or to add iron pellets to the coal. High iron coals always have high sulfur because the predominant form of iron in coal is iron sulfide (pyrite). Therefore, coal blending is prohibited by law due to increased sulfur emissions. A third alternative is to grind the coal going into the cyclone furnace much finer in order to increase the percentage of combustion that occurs for coal particles in flight. This option requires expensive modifications or replacement of grinding equipment, but moreover, it is counter to the original design and intent of the cyclone furnace and seldom solves the problem. All of these alternatives are much more expensive than the use of this byproduct material. Also, the smaller particle size of the iron byproduct material is better than larger forms of iron because the surface area of the fluxing material in contact with the slag drives the speed of a fluxing reaction. Therefore, the larger surface area of the dust compared to 1/4-inch pellets promotes fast and efficient fluxing.

Because of the small size of much of the available byproduct material, it can result in high fugitive dust emissions during handling and transportation. Therefore, a key step in this invention is to treat the material to provide acceptable dusting characteristics. The treatment can take place at the source of the material, at a transportation terminal, or at the plant site. There are several different types of treatment including:

- Adding water to the material. Laboratory tests have confirmed that the BOF dust is hydrophilic and mixes well with water. Adding water to the material forms a cohesive layer on the wetted surface after drying, which will eliminate fugitive emissions from the pile.
- The hydrophilic nature of the iron materials also means that they can be mixed as a slurry and made into any form desirable for shipping. Briquettes of the material can be made to decrease dust emissions during handling.
- Chemicals can be added to the slurried material to increase the cohesiveness of the final material. Laboratory tests have shown that xanthum gum and phosphoric acid lead to very cohesive products.

- Spraying with conventional dust suppression chemicals such as calcium lignosulfonate can treat the material to prevent handling problems. This material is commonly used to reduce coal dust emissions, and can be applied at a range of concentrations from 1% to 10% at a cost of $0. 40 to $4. 00 per ton.

The byproduct iron material must be shipped from the source to the power plant. Shipping the material from the source to the furnace will be the most expensive part of the process. The material can be shipped by truck, rail, or barge. It is important to minimize the distance being shipped and the number of transfers.

The next step in the process is mixing the material with the coal and feeding to the furnace. The iron fluxing material can be added at a variety of locations including:

- Mixing with the coal at a shipping terminal
- Adding to the coal reclaim belt
- Adding to the coal bunkers
- Using an eductor to aspirate the material and add to the coal or primary air streams.

The final step in the process is to control the feed rate of the material. This can involve either feed forward or feedback control. The feed forward control would be based upon the chemical analysis of the coal being feed from the boiler. Feedback control could come from a variety of measured characteristics of boiler operation and downstream components such as:

- LOI as measured by on-line furnace analyzer.
- Carbon content in ash as determined from ash samples extracted from the flue gas or precipitator hopper.
- Furnace exit gas temperature, which will decrease with less coal carryover from the cyclones.
- Slag optical characteristics such as emissivity or surface temperature.
- Slag tap flow monitoring.
- Stack opacity.

The preferred feed system for cyclone boilers has been discussed with reference to Figures 4 and 5. The fluxing agent is transported pneumatically from covered railcar or truck to a storage silo where it is disengaged from the transport air by a bin vent filter. Level indicators in the silo show when the silo is full or nearing empty. The fluxing agent is discharged from the storage silo to a weigh feed bin through a rotary valve to the coal line. The mixture of coal, fluxing agent, and conveying air are then carried to the cyclone burner.

In one formulation, a zinc mineralizer is used.

- The current additive embodiment contains 2-8% zinc. Zinc is a known mineralizer in the cement industry. Mineralizers are substances that reduce the temperature at which the cement clinker sinters by providing more contact points for mass transfer. As such, mineralizers could enhance the rate at which iron fluxes with PRB coal ash. A range of 0. 5-15% zinc is preferred in this application. A range of 2-8% is more preferred.
- The dusty, powdered iron material that is described in the patent application is extremely cohesive, and thus has a tendency to form dense, hard deposits in the delivery system. A number of flow aids and abrasive materials can be added to the material to aid in its handling. Possible flow aids include less than 5% of: ethylene glycol, proprietary agents known as "grind aids", and any other substance intended to reduce particle to particle attraction or sticking through electrostatic or mechanical means. Also included are any of a number of abrasive agents in the amount of 2-20% by weight. These agents include sand, blasting grit and boiler slag.
- Results of testing to date:
    - The iron-containing additive fed at a rate of about 20 lb/t coal allows slag to flow at lower temperatures. As a result, the boiler is able to operate overnight at lower load (60 MW without the additive, 35 MW with it) without freezing the slag tap and risking a boiler shutdown. The advantage is that the boiler can be operated at lower load (and more efficient units can operate at higher load) when the price of electricity is below the marginal cost of generating the electricity, thus saving on fuel costs. A rough estimate of the cost savings for KCBPU is about $200K/y.

- The iron-containing additive allows the cyclone boiler combustion process to operate more efficiently. These boilers are designed to burn the coal in a slag layer coating the cyclone barrel. When burning PRB coal, this slag layer is generally too thin and watery to capture the majority of the coal. Thus the coal burns in flight. This causes an increase in unburned coal and a decrease in boiler efficiency. To counteract this effect, additional air is supplied to the boiler and the coal is crushed more finely. This further decreases the boiler efficiency and increases the auxiliary power required to operate the boiler. Video recordings have shown that, with the additive, less unburned coal blows through the cyclone, which implies that the combustion process is operating closer to the way cyclones were designed to run.